IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

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JHU/APL Docket No. 1403-SPL

Serial No.: 09/401,701 Group Art Unit: 2857

Filed: 9/23/99 Examiner: Tsai, C.

Inventors: Carl V. Nelson
Bryan C. Jacobs

Title: MAGNETIC SENSOR SYSTEM FOR FAST-RESPONSE, HIGH RESOLUTION, HIGH ACCURACY, THREE-DIMENSIONAL POSITION MEASUREMENTS

APPELLANTS' BRIEF (37 CFR 1.192)

Assistant Commissioner for Patents
Washington, D.C. 20231

Dear Sir:

This brief, transmitted in triplicate (37 CFR 1.192(a)), is in furtherance of the Notice of Appeal filed in this case on November 25, 2002. The fee required under §1.17(c) is provided for in the accompanying Transmittal of Appeal Brief.

1. REAL PARTY IN INTEREST:

The real party in interest in this appeal is:

The Johns Hopkins University
34th and Charles Streets
Baltimore, MD 21218

2. RELATED APPEALS AND INTERFERENCES:

There are no related appeals and interferences.

3. STATUS OF CLAIMS:

a. Claims 1-14 were in the application as filed.

b. No claims have been amended.

I hereby certify that this correspondence is being deposited with the United States Postal Service with sufficient postage as first class mail in an envelope addressed to Assistant Commissioner for Patents, Washington, DC 20231 on January 27, 2003.

Francis A. Cooch 1/27/03
Signature Date

c. Claims 1-14 are pending and stand rejected.

d. **Claims 1-14 are on appeal** (See Appendix).

4. STATUS OF AMENDMENTS:

No amendment was filed subsequent to final rejection.

5. SUMMARY OF THE INVENTION:

a. Background

The invention relates generally to sensor systems and, more particularly, to a system capable of fast-response, high resolution, high accuracy three-dimensional position measurement using magnetic sensors.
(See specification, page 1, lines 17-19.)

Various systems have been proposed for detecting the position and/or orientation of an object using magnetic or electromagnetic fields. These systems typically employ field transmitters, such as electromagnet coils, disposed at known locations or in a fixed reference frame, and a sensor, such as a coil or other transducer mounted to the object to be located. Each transmitter projects a field varying in space in a fixed frame of reference. The pattern of variation in space for each transmitter is different than the pattern of variation for each other transmitter.

For example, the transmitters may be identical to one another but disposed at different locations or in different orientations. The field patterns of the transmitters are thus displaced or rotated relative to one another, and relative to the fixed frame of reference. The sensor on the object detects the parameters of the field prevailing at the location of the object as, for example, the magnitude and/or direction of the field at the object or the magnitude of individual components of the field at the object in one or more pre-selected directions. The transmitter may be actuated in a predetermined sequence so that at any time only one transmitter is active and therefore the field prevailing at the object is only the field contributed by one transmitter, plus a background field due to the Earth's magnetic field and other environmental sources.

Alternatively, the transmitters can be driven at different frequencies so that components of the signal from the sensor varying at different frequencies represent contributions to the field at the object from different transmitters simultaneously. Based upon the detected parameters of the fields from the individual transmitters, and the known pattern of variation of the field from each transmitter, a computer system calculates the position and orientation of the sensor, and hence the position of the object bearing the sensor, in the fixed frame of reference of the transmitters. In a variant of this system, the object to be located carries the transmitters, whereas a plurality of sensors are disposed at various locations or orientations in the fixed frame of reference. The location and/or orientation of the object is deduced from signals representing the parameter of the field prevailing at the various sensors.

(See specification, page 1, lines 24-36, and page 2, lines 1-18.)

Prior art systems are in need of improvement due to several deficiencies. First, some systems use a limited number of transmitters and thus can operate over only a limited range. Second, some systems require a special orientation of the transmitters and/or receivers and are thus limited in applications where such special orientation conditions are not feasible. Third, because the magnetic fields from typical transmitters (i.e., dipole field) vary approximately as the inverse cube of distance from the transmitter, the signal detected by the receiver is very small at long range, yielding a limited effective range of operation and/or the resolution/accuracy of the sensor is also limited.

To overcome the range limitations, received signals from a sensor are time-averaged to reduce environmental and electronic noise effects. The time-averaging increases the signal to noise ratio (SNR), yielding improved range, resolution, or accuracy (or all of the above). The trade-off is that such time-averaging slows the sensor's response time, so that the sensor cannot respond to sudden positional changes (i.e., velocity or acceleration).

Further, in some applications (e.g., car crash test dummy applications), the desired parameter is not just position, but speed and/or acceleration of the test object. To calculate velocity and acceleration, one must differentiate the position data resulting in noisy data or reduced accuracy/resolution.

(See specification, page 3, lines 19-37, and page 4, lines 1-2.)

b. Applicants' Invention:

Figure 1 shows a basic overview of the system of the invention for measuring position in three dimensions. The system uses an array of multiple, arbitrarily oriented magnetic field transmitters (1) in a fixed reference frame. The system also employs an array of multiple, calibrated, arbitrarily oriented magnetic field receivers (2), located on the test object (3) in a reference frame fixed to the test object (3), and measures the magnetic field components created by the array of transmitters (1). For AC magnetic field transmitters, the transmitter frequencies are different; for DC magnetic field transmitters, the transmitters are operated sequentially. The array of magnetic field transmitters (1) generate a spatially varying magnetic field in the sensing volume. A method is employed to sort the magnetic field components from the receiver signal (e.g., for an AC transmitter system with multiple frequencies, one can use a synchronous demodulator or notch filter to isolate the multiple frequencies). A physics-based extended Kalman filter is used to solve the non-linear inverse measurement problem and provide 3-D position, 3-D velocity and 3-D acceleration of the test object (3). (See specification, page 7, lines 8-23.)

Figure 3 shows a simplified diagram of a sensor system that was constructed to demonstrate the invention. Features of the sensor system in Figure 3 include: three dipole transmitters (1) mounted at known locations; transmitters (1) operating at three frequencies (2); three orthogonal induction coil receivers mounted on a plastic cube (3) (fixed rigid body); receiver signals are amplified (4); receiver signals are demodulated using lock-in amplifier technology (5) (alternatively, the multiple frequencies in the receiver signal could be digitally, synchronously demodulated by using a high-speed analog-to-digital converter); and employing an extended Kalman filter to solve the non-linear measurement problem and provide position, velocity and acceleration estimates.

Features of the reduced to practice system and algorithm in Figure 4 include the following: the power oscillators (1) drive the magnetic field transmitters (2), the magnetic field is sensed by magnetic field receivers (3) which are then amplified and synchronously demodulated by nine-channel lock-in amplifiers and filters (4), then the output voltage for each frequency of the lock-in amplifiers (4) is sent to the total magnetic field calculator (5) where the voltages are converted into magnetic field values.

An extended Kalman filter/smoother (6) uses the calibration equation of magnetic field as a function of position for each frequency and each receiver (3) to calculate position, velocity and acceleration.
(See specification, page 8, lines 8-29.)

The Biot-Savart law was integrated for the transmitter geometry and certain approximations to express the magnetic field as a sum of trigonometric functions were made. Faraday's law on induction was then applied to determine an expression for the induced pick-up coil voltages, the envelopes of which are produced by lock-in amplifiers and sampled by an analog to digital converter. The measurement equation is formulated as a non-linear function of the (assumed) six degrees of freedom of the rigid body. The partial derivatives of the vector measurement equation are evaluated and used by an extended Kalman filter to provide estimates of the position, velocity, and acceleration of the rigid body. In general, any problem specific constraints and dynamics can be modeled in the Kalman filter. However, it is typically assumed that the rigid body is free to experience linear and angular accelerations which are modeled as second order Gauss-Markov random processes.
(See specification, page 8, lines 33-37, and page 9, lines 1-7.)

The present invention includes several advantages, as follows. The sensor system can use an arbitrary number of magnetic field transmitters and magnetic field receivers. The transmitters and receivers can be oriented in an arbitrary geometry relative to a fixed reference frame of the object whose position is being measured. Because multiple transmitters and receivers can be used in the sensor system, two major advantages are realized. First, multiple transmitters can be used to provide signal coverage in a large sensing volume, while most magnetic position sensing systems are limited by the range of the magnetic transmitters and the sensitivity of the magnetic field receivers. Second, the sensor system can operate in close proximity to metal surfaces and objects. For the case of an AC transmitter field, eddy currents generated in the metal by the magnetic transmitter can be modeled and accounted for in the processing algorithm, i.e., the nearby metal generates 'virtual' magnetic field transmitters that can be treated as additional transmitters with their own unique position and orientation.
(See specification, page 5, lines 23-36, and page 6, lines 1-2.)

Because of the unique nature of the physics-based processing algorithm, the sensor system does not require the receiver signals to be averaged. Therefore, the measurements can be taken at high speed, thus giving the sensor the advantage of high speed response. Alternatively, in high magnetic noise environments where response speed is not a requirement, the sensor system can have high spatial resolution/accuracy by averaging the receiver signals (trade-off of speed vs. spatial resolution). For cases where there is high signal-to-noise, the sensor system provides both high speed response and high spatial resolution and accuracy.

(See specification, page 6, lines 23-32.)

6. ISSUES:

a. Whether claims 1-7 are unpatentable under 35 USC §103(a) over U.S. Patent No. 5,646,525 to Gilboa in view of U.S. Patent No. 3,996,590 to Hammack.

b. Whether claims 9-14 are unpatentable under 35 USC §103(a) over Gilboa in view of U.S. Patent No. 5,307,072 to Jones, Jr. and Hammack.

c. Whether claim 8 is unpatentable under 35 USC §103(a) over Gilboa in view of Hammack as applied to claim 1, and further in view of Jones, Jr.

7. GROUPING OF CLAIMS:

The claims grouped under each rejection stand or fall together except that claim 14 is believed to be separately patentable from claims 9-13 for the reasons set forth in the argument below.

8. ARGUMENT:

a. The Examiner has rejected claims 1-7 under 35 USC §103(a) as being unpatentable over U.S. Patent No. 5,646,525 to Gilboa in view of U.S. Patent No. 3,996,590 to Hammack.

As noted in Applicants' specification and claims, Applicants' invention uses a plurality of magnetic field transmitters and at least one magnetic field receiver, transmitters and receivers capable of being geometrically arbitrarily oriented relative to a fixed reference frame, and determines position, velocity and acceleration of an object using magnetic field currents. Gilboa discloses an apparatus for determining the position and orientation of a helmet worn by a crew member in a vehicle (see abstract, lines 1-2). As noted by the Examiner, Gilboa does not disclose a plurality of magnetic field transmitters. Furthermore, Gilboa discloses, as its preferred embodiment, orthogonal sensors/detectors (col. 2, lines 33-50; Fig. 5) whereas, as noted, Applicants' invention, as claimed, is capable of being geometrically arbitrarily oriented (see also, e.g., Applicants' Fig. 2C). Hammack, used by the Examiner in combination with Gilboa to reject claims 1-7, has nothing to do with magnetic fields and everything to do with the use of Doppler to measure position (see col. 5, lines 45-48). In fact, the Examiner's cite to Hammack's specification, i.e., col. 20 lines 39-41, for the use of a plurality of magnetic field transmitters (with broad beamed antennas) in this rejection is to an embodiment for a space track system to detect the presence of a space vehicle with the system having a coverage of an area 1500 miles in diameter to an altitude of over 2000 miles. This has nothing to do with Applicants' invention and there is no suggestion in either Hammack (space track system) or Gilboa (helmet locator) for combining the two references as the Examiner does.

Applicants submit that the use of Hammack in this rejection is improper for the reasons stated above and, therefore, Gilboa alone is insufficient to render claims 1-7 obvious.

b. The Examiner has rejected claims 9-14 under 35 USC §103(a) as being unpatentable over Gilboa in view of U.S. Patent No. 5,307,072 to Jones, Jr. and Hammack.

For the reasons stated above in Applicants' response to the Examiner's use of Hammack to reject claims 1-7, Applicants submit that the use of Hammack in this rejection is also improper and that, without Hammack, the rejection of claims 9-14 cannot stand. Furthermore, and with all due respect, Applicants can find nothing in the entire

Gilboa reference that discloses treating eddy currents generated in metal surfaces as virtual magnetic field transmitters as recited in claim 14. Applicants respectfully disagree with the Examiner's argument that Fig. 6 of Gilboa discloses treating eddy currents as virtual magnetic field transmitters. As the Examiner notes, Fig. 6 is a plot of a magnetic field and magnetic potential of a rotating dipole, but Applicants do not agree that Fig. 6 discloses a virtual dipole created by a dipole transmitter a distance from a metal surface. The Examiner states that Fig. 6 discloses this but does not explain how.

c. The Examiner has rejected claim 8 under 35 USC 103(a) as being unpatentable over Gilboa in view of Hammack as applied to claim 1, and further in view of Jones, Jr.

For the reasons stated above in Applicants' response to the Examiner's use of Hammack to reject claims 1-7, Applicants submit that the use of Hammack in this rejection is also improper and that, without Hammack, the rejection of claim 8 cannot stand.

9. SUMMARY:

For the foregoing reasons, Applicants submit that the Examiner's rejections of claims 1-14 were erroneous, and reversal thereof is respectfully requested.

Respectfully submitted,

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Date January 27, 2003

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Enclosure: APPENDIX: Claims on Appeal (Serial No. 09/401,701)

APPENDIX
CLAIMS ON APPEAL
(Serial No. 09/401,701)

1. A magnetic sensor system for determining the three-dimensional position, velocity and acceleration of an object utilizing magnetic field currents, said sensor system being capable of operating within close proximity to metal surfaces and metal objects, comprising:

an object, the position, velocity and acceleration of which are to be determined;

a three-dimensional fixed reference frame of known dimensions, wherein said object is located within said fixed reference frame;

a power source capable of generating a magnetic field within said fixed reference frame;

a plurality of magnetic field transmitters, said transmitters operatively interconnected to said power source and capable of being geometrically arbitrarily oriented relative to said fixed reference frame;

at least one magnetic field receiver, said receiver capable of receiving electronic signals from said transmitters and further capable of being geometrically arbitrarily oriented relative to said fixed reference frame;

a programmed computer, said computer capable of receiving said signals from said receiver and further capable of calculating the position, velocity and acceleration of said object based upon said signals.

2. A sensor system as claimed in claim 1, wherein said power source is capable of generating DC magnetic fields, AC magnetic fields, pulsed DC magnetic fields, or combinations thereof.

3. A sensor system as claimed in claim 1, wherein said transmitters are selected from the group consisting of induction loops, permanent magnets, and combinations thereof.

4. A sensor system as claimed in claim 1, wherein said receivers are selected from the group consisting of induction loops, Hall effect sensors, and magneto-resistive magnetic field sensors.

5. A sensor system as claimed in claim 1, wherein said sensor system is capable of recording individual receiver signals at high speed.

6. A sensor system as claimed in claim 1, wherein said sensor system is capable of being self-calibrating.

7. A sensor system as claimed in claim 1, wherein said transmitters are electronically compatible with said receivers.

8. A sensor system as claimed in claim 1, wherein said transmitters are capable of generating frequencies in the range of 20-100 KHz.

9. A method for determining the position, velocity and acceleration of an object, comprising:

providing a three dimensional fixed reference frame of known dimensions;

providing an object, the position, velocity and acceleration of which are to be measured;

generating electrical current from an oscillator;

delivering said current from said oscillator to a power amplifier;

directing said amplified current from said amplifier to a plurality of transmitters;

generating a magnetic field from said transmitters in said reference frame;

receiving said magnetic field signal from said transmitters into at least one receiver;

demodulating and amplifying said received magnetic field signal into magnetic field components from said receiver signal, wherein said output from said amplifier is proportional to said magnetic field components;

applying a mathematical filter to said demodulated and amplified signal; and

applying a mathematical algorithm to calculate the position, velocity and acceleration of said object.

10. A method as in claim 9, wherein said electrical current is selected from the group consisting of an alternating current source, a direct current source, a pulsed direct current source, and combinations thereof.

11. A method as in claim 9, wherein said mathematical algorithm mathematically models said transmitters as dipoles, said algorithm further uses total field and vector magnetic field mathematical components to calculate said three-dimensional position of said object.

12. A method as in claim 9, further comprising placing calibrated magnetic field receivers at a known location in an uncalibrated transmitter geometry, wherein said algorithm determines the location of said transmitter in said fixed reference frame.

13. A method as in claim 9, wherein said algorithm mathematically averages said signals from said receivers.

14. A method as in claim 9, wherein said algorithm mathematically treats eddy currents generated in metal surfaces and objects nearby said transmitters as virtual magnetic field transmitters, said algorithm further calculating the position and orientation of said virtual magnetic field transmitters.